PRESSURE SIGNATURES OF A CYLINDRICAL BODY MOVING IN AQUEOUS SOLUTIONS OF POLY (ETHYLENE OXIDE)

By

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THESIS

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Lieutenant, United States Navy
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ABSTRACT

A whirling arm apparatus was successfully developed and tested for investigating the pressure signatures of submerged bodies of length less than one foot. The pressure signature of a cylindrical body, nine inches long and one inch in diameter, moving at constant velocities of 1.57, 1.84, and 2.36 m/s in aqueous solutions of Poly(Ethylene Oxide) WSR-301 at concentrations of 0, 50, 100, and 200 wppm was investigated under laminar flow conditions; Reynolds numbers, based on length, were in the range from 3.6×10^5 to 5.4×10^5. A regular laminar flow pattern was investigated utilizing the body with a hemispherical bow and tapered stern, and a laminar flow pattern with forced fluid separation followed by reattachment was investigated by utilizing a squared-off bow and a tapered stern. A Barium Titanite crystal hydrophone was used as the sensor. No apparent difference in the pressure signature was found which could be attributed to the addition of the polymer into solution.

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ACKNOWLEDGEMENTS

The author wishes to acknowledge Milt Andrews and Bob Moeller for their fine technical expertise in constructing and maintaining the apparatus, Bob Smith for his design of the collumated light-beam trigger, Jack Brennan for "bird-dogging" equipment, and Barney Taylor and Fred Lasher for their assistance in photography. Also, thanks to Gene Bleasdale, Kistler Instrument Corporation Representative, for his assistance in the system frequency response calculations, and to Tom Barrett, MB Electronics District Manager, for his assistance in solving the vibration problems. Special appreciation is due Dean Carl Menneken for devoting his valuable time for much discussion, and to Maryann Clarey for typing the final manuscript. Finally, this project would not have been possible without the capable direction of Associate Professor James Sanders and the understanding of my wife.

I. INTRODUCTION

A. BACKGROUND

In 1948 B.A. Toms [14] reported to the scientific community his observations on the reduction of drag brought about by the addition of polymers to flow in straight pipes at high Reynolds numbers. This phenomenon received little attention until 1959 when additional observations of drag reduction were reported by Shaver and Merrill [13] and Dodge and Metzner [4]. These initial reports, showing drag reduction of up to eighty percent, stimulated researchers both in industry and in the academic community. From 1959 until the present time, there has been an almost continuous flow of reports of investigations into this phenomenon, and many practical industrial applications of the phenomenon of drag reduction by polymer additives have been suggested.

B. THEORETICAL MECHANISMS

The exact mechanism of drag reduction by the addition of long-chain macromolecules into fluid solution has not been explained, and many researchers have hypothesized that there may, in fact, be several mechanisms by which the phenomenon occurs. McNally [10], in a recent investigation into this phenomenon, attempted to explain it from an intramolecular action point of view and concluded, in part, that "a particulate theory will probably be required for understanding the phenomenon. Such a theory will require both a

better understanding of the structure of turbulence and of the solution behavior of macro-molecules." A recent investigation by Kinnier [8] showed, from a different point of view, that evidence exists to support a conclusion that the in-solution volume occupied by the drag-reducing agent, Poly(Etheylene Oxides), may be the key to understanding the phenomenon. Hence, there presently exists no satisfactory explanation of the mechanism by which certain polymers in aqueous solution cause such remarkable changes in viscous drag, and it appears that such an explanation is some years in the future.

C. OTHER RESEARCH

Even though primary research efforts into the properties of aqueous solutions of Poly(Etheylene Oxides) have been directed toward observations of drag reduction, some investigators have reported interesting effects other than drag reduction. Sendek [12] observed that the turbulent flow noise caused by spheres falling in water was significantly decreased by introducing small amounts of Poly(Etheylene Oxide) into aqueous solution. Furuike [5] reported observations of both self-noise reduction and vibration damping of a waterborne test vehicle when travelling in aqueous solutions of Poly(Etheylene Oxide).

D. DRAG-REDUCING AGENTS

The substances possessing the ability to reduce drag are long-chain molecules (macromolecules) of an organic-polymer composition. Some of these substances are naturally occurring, such as Guar Gum,

while others must be manufactured. The drag-reducing agents most widely investigated have been the Poly(Etheylene Oxides), and the most effective member of this family has been found to be that with the largest molecular weight. A readily available commercial grade, WSR-301, is produced by Union Carbide Corporation, and has been widely used in investigations into this phenomenon.

E. EXPERIMENTAL LOGIC

Since the precise mechanism of drag reduction caused by long-chain macromolecules in solution is unknown, there may be effects upon the flow other than drag reduction and a decrease in radiated flow noise. Associated with a body in translational motion in any medium there is a characteristic kinetic energy head or pressure front created within the medium and travelling with the body. Whether this pressure front remains the same or is altered when drag-reducing agents are added is unknown.

F. EXPERIMENTAL INTENT

The experimental intent, then, was to investigate the kinetic energy head or pressure signature associating with a circular cylinder travelling at constant velocity in water and in aqueous solutions of poly(ethylene oxide) under both laminar and forced fluid separation flow conditions.

G. PREDICTED DIFFICULTIES

Attendant to the investigation were the problems of creating a satisfactory environment in which the pressure signature of a model

could be detected above noise. Since laboratory space at the Naval Postgraduate School limited overall apparatus size, the model had to be small. A facility capable of measuring the pressure signatures of small models had not been previously built and tested.

H. EXPERIMENTAL IMPORTANCE

The importance of this query lies in the possibility of being able to explain more about the mechanism by which poly(ethylene oxide) operates in aqueous solutions, and in that Naval application of drag-reducing agents in such areas as mine warfare would be significant if an alteration of the kinetic energy head could be produced.

I. PREVIOUS WORK

Previous experimental and theoretical work in the field of pressure signatures has been centered at the Naval Ship Research and Development Center and performed under the direction of Dr. Avis Borden [2]. This work was performed with water and did not include any investigation into drag-reducing agents. Dr. Borden retired from active service in August of 1970, and with her went much of the theoretical and technical know-how in the field of modeling pressure signatures. Presently, there are no known scientists working in this field with active research projects.

Dr. Borden and her associates did develop a computor program which would calculate the pressure signature of a given hull shape based upon a theoretical source-sink distribution. This program calculates the waveform, relative magnitudes, and absolute magnitudes of a pressure signature. The output of this program could then be compared with the results obtained from modeling the hull and conducting large scale towing tank experiments. Agreement between the modeling and theoretical results would in turn, confirm the theoretical source-sink distribution upon which the theoretical results are based.

II. APPARATUS

A. GENERAL DESCRIPTION

The experiment was conducted in a circular towing tank with the model suspended from a whirling arm. The annular tank is constructed of 5/16-inch rolled sheet steel and has an outside radius of $3\frac{1}{2}$ feet with an inside radius of 2 feet, so that the fluid channel is $1\frac{1}{2}$-feet wide; the tank walls are 21-inches high.

The advantages of utilizing an annular tank with a whirling arm for this type of experimental investigation are that a high number of event reproductions could be made within a fairly short time under approximately identical conditions, and that the entire data run can be easily observed.

However, there are two significant disadvantages to this arrangement. The first is that the motion of the body during a run sets the fluid into motion, so that during repetitive revolutions, the body does not pass thru completely still fluid. The second disadvantage is that a tank of this design and construction possessed a large number of natural vibration modes; hence, a severe isolation problem had to be solved prior to conducting the experiment.

B. WHIRLING ARM AND DRIVE TRAIN

The whirling arm is $5\frac{1}{2}$-feet long and constructed of 3/16-inch aluminum T-bar with two $5\frac{1}{2}$-foot lengths of 3/4-inch outside diameter,

1/16-inch wall thickness, aluminum pipe spot welded to the inside corners of the T-bar to provide added stiffness. The whirling arm is suspended 1 1/8 inches above the upper rim of the tank.

The arm is driven by a vertical reduction and gearing arrangement, (MASTEReducer, Type WR214, manufactured by Reliance Electrical and Engineering Company) which in turn is driven thru a pully and belt arrangement by a ½ horsepower electric motor.

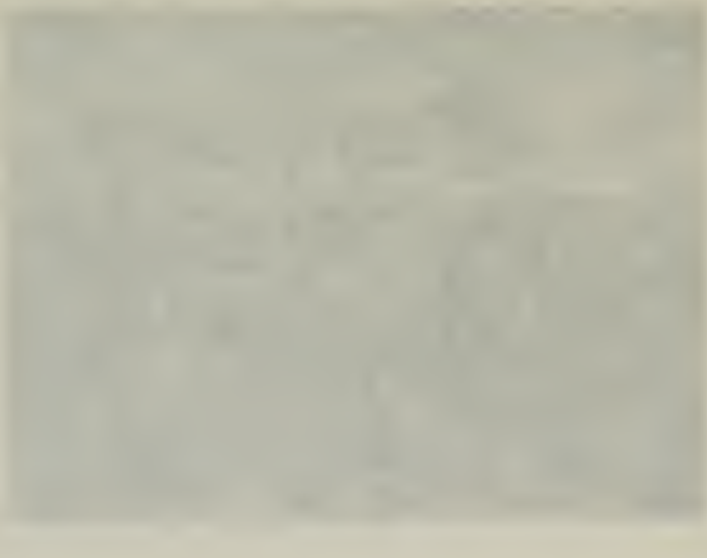
The motor speed was controlled by a rehostat so that the rotational rate of the whirling arm could be varied from 3.75 rpm to 30 rpm. Since in a single revolution the tow path was 5.42 meters, the speed of the model could be varied from 0.34 to 2.71 meters/second.

C. TOWING STRUT

The model was suspended from the whirling arm by a one-foot long hollow symmetric hydrofoil strut made of an aluminum alloy. Two 1/8-inch diameter threaded steel rods were permanently fixed to the model and passed completely through the strut to provide rigidity. The strut cross section is shown in Figure 1. The strut and model were solidly fixed together and to the whirling arm as shown in Figure 2. The model was positioned in the middle of the fluid-channel cross section, 4 3/8 inches from the bottom of the tank. Two fluid levels were used during the experiment. One was 7¼ inches so that about 1½ inches of the strut were submerged, and the other level was 14½ inches.

Figure 1. Strut Cross-section

Figure 2. Strut and Model Mounting



D. COLLUMATED LIGHT BEAM TRIGGER

To mark the passage of the body, a light beam trigger, manufactured locally at the Naval Postgraduate School, was utilized. The trigger is battery powered and its operating element is a high speed computor switching diode. When activated, the trigger gives a negative 6-volt voltage impulse. This trigger is mounted above the fluid level in the tank with a collumated light beam projected radially across the channel. When the supporting strut interrupts the light beam, the device triggers the voltage impulse.

E. HYDROPHONE

The pressure variations associated with the passage of the model were sensed with an omni-directional crystal hydrophone, Model LC-32, Serial number 204, manufactured by Atlantic Research Corporation of Alexandria, Virginia. The open-circuit receiving sensitivity of the hydrophone is shown in Figure 3, and the physical dimensions of the hydrophone are shown in Figure 4.

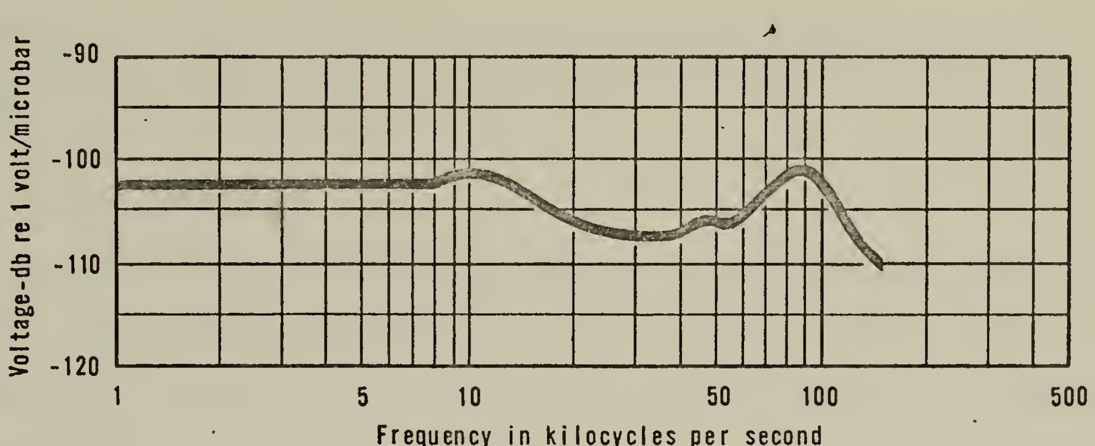


Figure 3. LC-32 Open Circuit Receiving Sensitivity

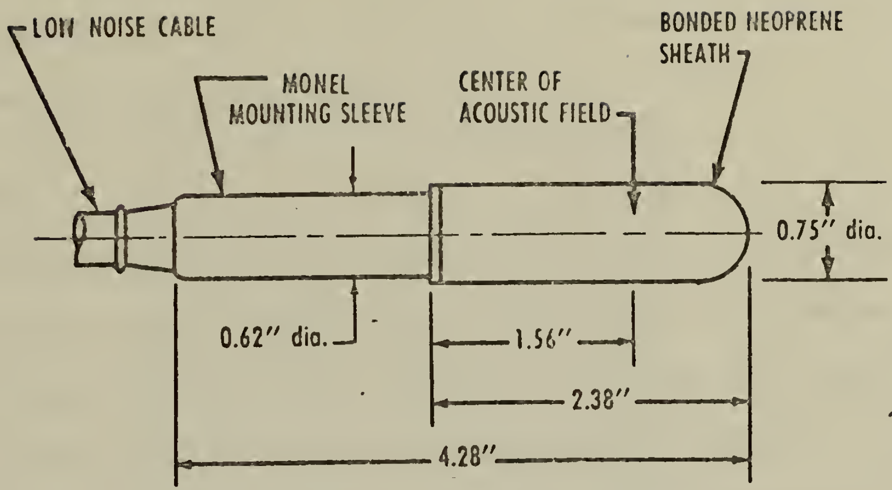


Figure 4. LC-32 Hydrophone Dimensions

The LC-32 was mounted directly below the path of the model and was placed horizontally on a piece of aluminum-doped rubber (3 3/4 inches by 3 inches) to vibration isolate it from the tank bottom. The vertical distance between the hydrophone and the model body was approximately 2 inches.

F. CHARGE AMPLIFIER

The output of the hydrophone was sent via low-loss coaxial cable into a Model 504 Charge Amplifier manufactured by Kistler Instrument Corporation of Clarence, New York. The Charge Amplifier was operated on SHORT time constant which provided on input resistance of 1,000 Megohoms, with the SENSITIVITY dial set to 1.6

and the RANGE dial to 5. These settings provided the best internal impedance matching available between the hydrophone and the Charge Amplifier with a correspondly good low frequency response. The low frequency roll-off was calculated to commence about 5 Hertz and is down 4 db at 3.2 Hertz.

G. MODEL

The modeled body was essentially a circular cylinder with different end caps. The cylinder was one-inch in diameter, six-inches long, and was made of aluminum. The end caps were threaded into the body on either end. End cap shapes of square, hemi-spherical, and taper were available; end cap lengths were 1 inch, 1 inch, and 2 inches respectively. Photographs of the model and strut combination with various end cap configurations are shown in Figures 5 and 6. The weight of the model and strut combination, including two end caps was approximately 0.4 Kg.

Model velocities were selected to provide Reynolds numbers, (based upon model length and the kinematic viscosity of water) from 3.6×10^5 to 5.4×10^5. Since Reynolds numbers of magnitude 10^6 (based on length) are necessary for transition to turbulent flow on flat plates, the boundary layer remains laminar on the body when it has a smoothly curving bow and stern. When a square bow cap is used, the discontinuity will force fluid separation at the sharp edge; since the Reynolds number range is still in the laminar flow region, reattachment will occur on the model body. As far as the observed pressure signature is concerned, fluid

separation at the bow of the model increases the strength and rate of the first negative portion of the signature relative to that observed when the flow is completely laminar.

Figure 5. Body and Strut Combination with End Caps Shown

Figure 6. Body and Strut Combination with Hemispherical Bow and Taper Stern

H. OSCILLOSCOPE AND RECORD CAMERA

The equipment utilized to analyze the hydrophone output was a TEKTRONICS, Inc. Model RM503 Oscilloscope. It was fitted with a Dumont Laboratories type 302 Oscillograph Record Camera (POLAROID type 2614 Land Camera). POLAROID type 47, speed 3000, film was used in the camera.

III. EXPERIMENTAL CONSIDERATIONS

A. GENERAL VIBRATION

Because of the low level of the velocity head of the model used it was imperative that the fluid environment in which it operated be a quiet as possible and that the model itself be as vibration free as possible.

B. TANK VIBRATION ISOLATION

To isolate the tank from floor vibrations it was rested upon eight wooden struts which extended symmetrically from the inside edge of an octogonal wooden support frame. Interposed between the supporting frame struts and the tank bottom was Isomode Vibration Pad manufactured by MB Electronics of El Segundo, California. The padding was equally distributed on each strut. The amount of padding used was four thicknesses with the surface area calculated to provide an overall load of 50 psi when the tank was filled to a depth of 7¼ inches of water. The characteristics of the Isomode Vibration Pad for a 50-psi load are shown in Figure 7.

C. GEAR TRAIN TO WHIRLING ARM VIBRATION

To prevent vibration from the gear train passing to the model thru the whirling arm, the arm was similarly isolated utilizing the Isomode Vibration Pad and two neoprene washers and sleeves around the mounting bolts of the whirling arm. The details of

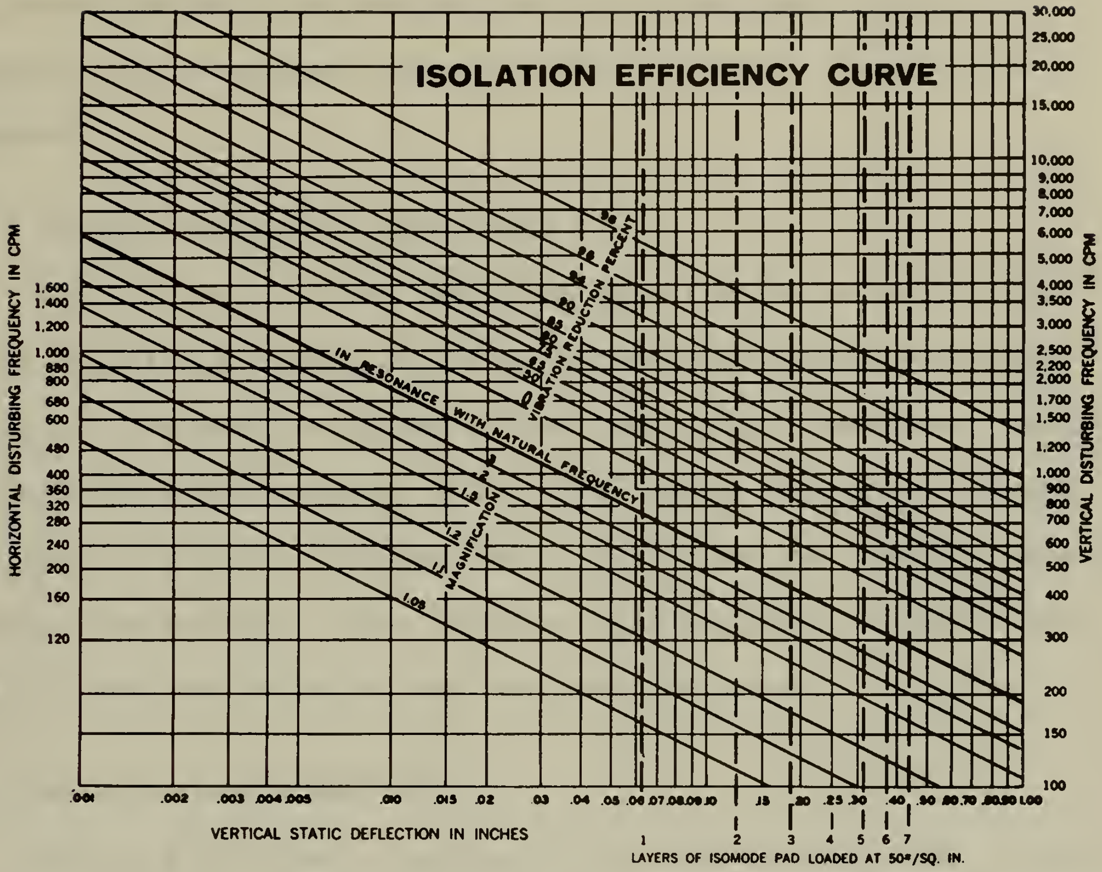
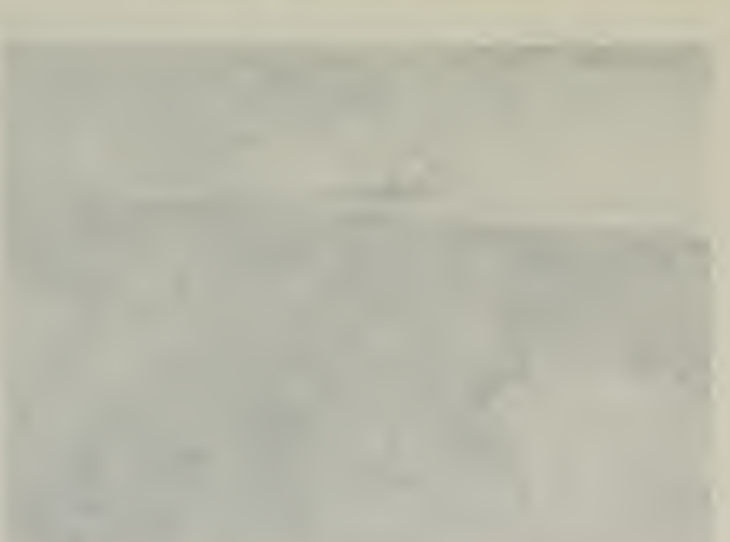


Figure 7. Characteristics of Isomode Vibration Pad

Figure 8. Mounting Details of Whirling Arm



this construction are shown in Figure 8. The four bolts which attached the whirling arm to the top of the gear train were appropriately torqued to provide 50 psi loading force on the padding.

D. AIRBORNE MOTOR AND GEAR NOISE

Motor and gear noise impinging upon the inside wall of the tank was also a source of energy which might excite the tank. Hence, a octogonal cylinder of 3/4-inch thick plywood was placed around the motor and gear train. The space between the wooden cylinder and the inside tank wall, 3 to 4 inches, was filled with fiberglass matting, and a layer of this matting, one-inch thick, also lined the inside of the octogonal cylinder.

E. WHIRLING ARM VIBRATION

During preliminary testing of the apparatus in water it was determined that the whirling arm exhibited an excessive 200 Hertz vibration which was then transmitted to the strut and model; a carrier of this frequency dominated the received pressure signature. To lower the resonant frequency of the whirling arm, a 26-lb lead weight was mounted on each end of the arm using one large C-clamp weighing $2\frac{1}{4}$ lbs each. The total added weight $56\frac{1}{2}$ lbs. The approximate center of gravity for these weights was 32 inches from the center of the whirling arm.

F. MODEL VIBRATION INTERFERENCE

During data runs at 200 wppm concentration and occasionally during runs at 100 wppm concentration, lateral vibration of the model was found to be causing interference which tended to smear the oscilloscope trace and made it difficult to discern the true pressure signature. To alleviate this problem, a standard laboratory clamp which weighed about the same as the model and strut combination (0.4 Kg) was attached to the strut mid-way between the whirling arm and the model. This decreased the lateral vibration interference to a reasonable level.

IV. POLYMER

A. TYPE OF POLYMER UTILIZED

The drag reducing agent used was PolyOx WSR-301, a commerical grade of Pcly(Ethylene Oxide) produced by Union Carbide Corporation. This same agent has been utilized in much prior experimental work associated with drag-reduction, since it had been shown to be the most effective drag-reducing agent because of the large size of its molecules (molecular weight $\sim 10^6$).

B. POLYMER MIXING TECHNIQUE

Adding the PolyOx to the water in the tank was accomplished by first creating a suspension of the PolyOx in Polyglycol, in which it is insoluble, in the ratio of 0.02 liters of Polyglycol to 1 gram of PolyOx. The suspension was then slowly added to the water stream from a hose as the tank was being filled.

The PolyOx, if added directly to water, tends to coagulate into multi-molecule groupings because of the large number of un-satisfied hydrogen bonds which it possesses. These groupings are visible as whispy strands of white material not unlike spun cotton.

To provide for thorough mixing, the whirling arm was slowly rotated for one hour with a 2-inch diameter cylinder vertically suspended from it; the cylinder extended to within one-inch of the tank bottom. The fluid was then aged for eighteen hours and again agitated in the same manner for another hour prior to commencing data runs.

V. EXPERIMENTAL PROCEDURE

A. GENERAL PROCEDURE

The experimental procedure consisted of rotating the whirling arm at constant speed and photographing the output of the hydrophone as displayed on the oscilloscope to determine the waveform of the pressure front generated by passage of the model. This comprised one data run. A water depth of 7¼ inches was used.

B. FLUID MOTION EFFECTS

During initial data runs in water it was obvious from the amount of difference between waveforms obtained on consecutive revolutions of the model that the surface waves in the tank were sufficient to interfere with the pressure signature as received at the hydrophone. This was particularly true at the two lower speeds where the extraneous fluid motion in the tank completely disguised the pressure signature. To overcome this interference, the model was photographed during its first revolution so that it would be passing thru still fluid. It was found that, by commencing the data run with the model about 270 degrees of rotation away from the hydrophone, the model acquired constant velocity at the light beam trigger without creating noticeable surface wave interference. It was necessary to stop the model and to wait approximately five minutes between data runs to allow the surface waves to die away.

Two exposures of each data run were made on each photograph. This provided an appropriate method of comparison, since it was unlikely that the fluid motion would be identical for two independent data runs. If any significant difference was seen, the entire two data runs were repeated on a new photograph.

C. PARAMETERS OF INVESTIGATION

Data runs were made at the same speed utilizing two different model configurations, hemispherical and square bows, both with taper stern. The hemispherical bow resulted in laminar flow, whereas the square bow forced fluid separation at the nose of the body.

Then, model speed was changed and the procedure repeated. Three different speeds were investigated; 1.57, 1.84, and 2.36 meters/second. The model speeds for each run were determined by time averaging over ten revolutions using the light beam trigger as start and stop pulses.

D. METHOD OF OBTAINING RESULTS

The output of the Kistler 504 Charge Amplifier.was fed directly to the RM503 Oscilloscope; the oscilloscope was set on external trigger, and the light beam trigger was located ahead of the hydrophone so that it would trigger the oscilloscope at the proper time to provide a good trace of the pressure signature as the model passed over the hydrophone. The distance at which the trigger was located from the hydrophone was approximately 14 inches for velocity 2.36 meters/second and somewhat less for the lower speeds.

E. CONCENTRATIONS OF POLYMER UTILIZED

Following all the data taking runs for water (0 wppm) a drag-reducing agent was added and the same data runs repeated for the new fluid. The concentrations of PolyOx examined in this manner were 50, 100, and 200 wppm. The tank was then drained, cleaned, and water was again utilized as the fluid to make a final set of runs for comparison purposes.

F. DETERMINATION OF STRUT CONTRIBUTION

To determine the effect of the strut upon the pressure signature received, the model was removed from the strut and it was then fitted with a flush end cap. Data runs were then made with the strut alone during the experiment at concentrations of 0 and 100 wppm.

G. DETERMINATION OF FREE SURFACE EFFECT

The effect caused by reflected pressure from the free air-water interface above the model on the received pressure signature was quantitatively determined by conducting additional data runs at a water depth of 14½ inches, double the normal depth, during laminar flow conditions at concentration 100 wppm.

VI. RESULTS

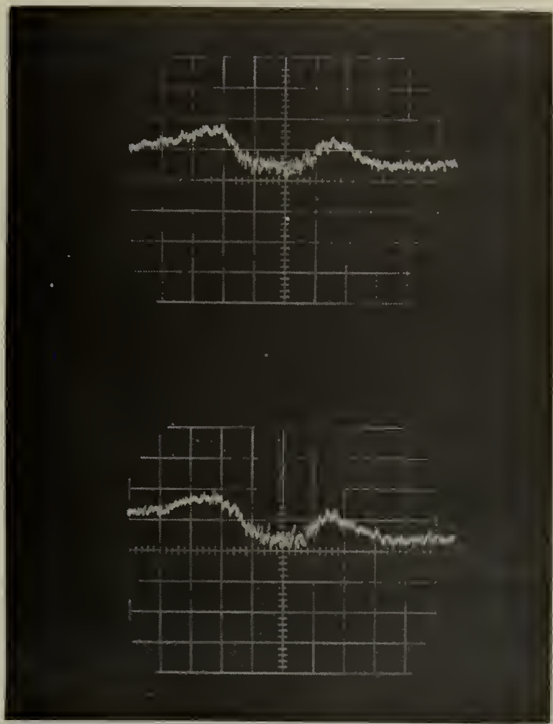
A. PHOTOGRAPHIC RESULTS

The photographic results obtained are displayed on the following pages according to the following keys:

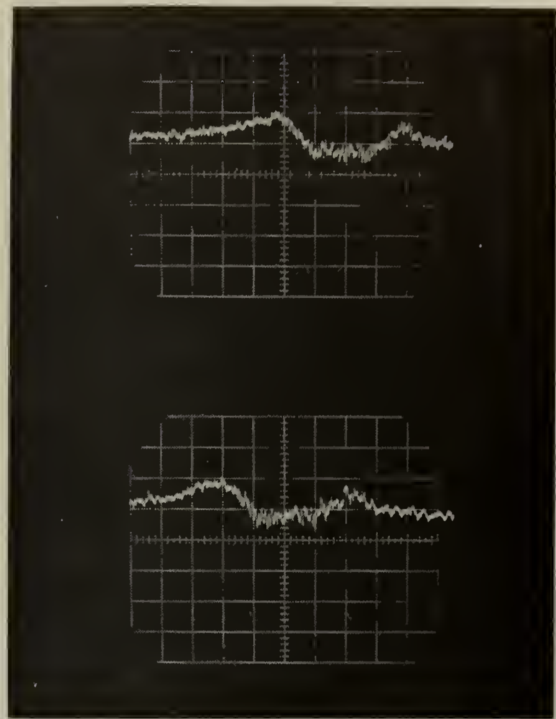
FOR LAMINAR FLOW	Figure	Velocity	Concentrations
	9	1.57 meters/second	0,50,100 wppm
	10	1.84 meters/second	0,50,100 wppm
	11	2.36 meters/second	0,100 wppm
	12	2.36 meters/second	50,200 wppm

FOR FORCED FLUID SEPARATION FLOW	Figure	Velocity	Concentrations
	13	1.57 meters/second	0,50,100 wppm
	14	1.84 meters/second	0,50,100 wppm
	15	2.36 meters/second	0,100 wppm
	16	2.36 meters/second	50,200 wppm

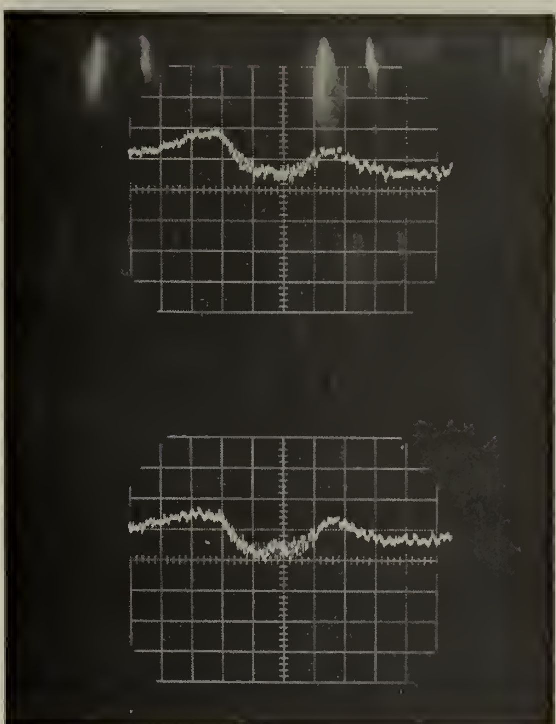
All photographs have the same scale factors of 50 milliseconds per division horizontally and 0.5 volts per division vertically.



0 wppm

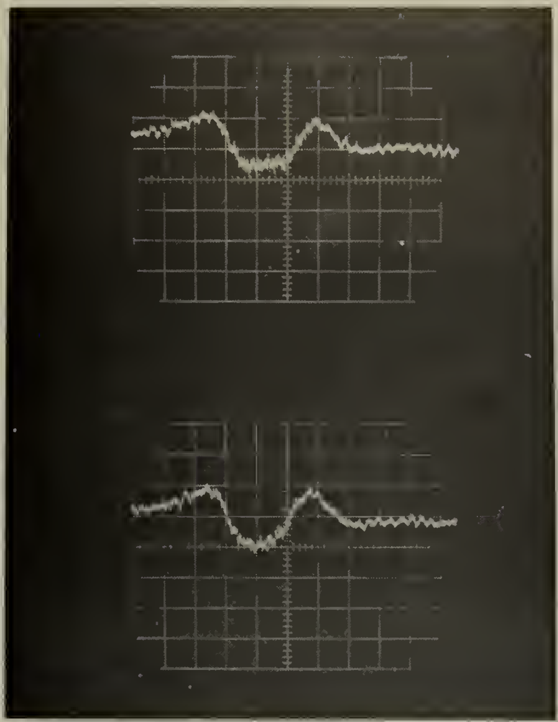


50 wppm

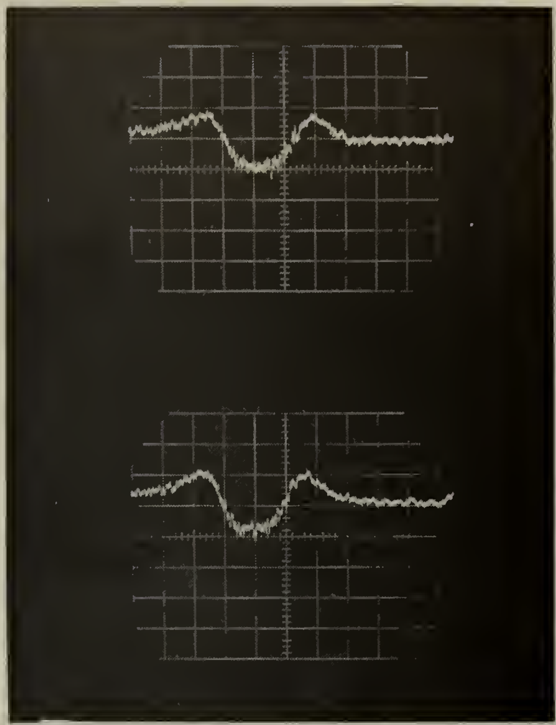


100 wppm

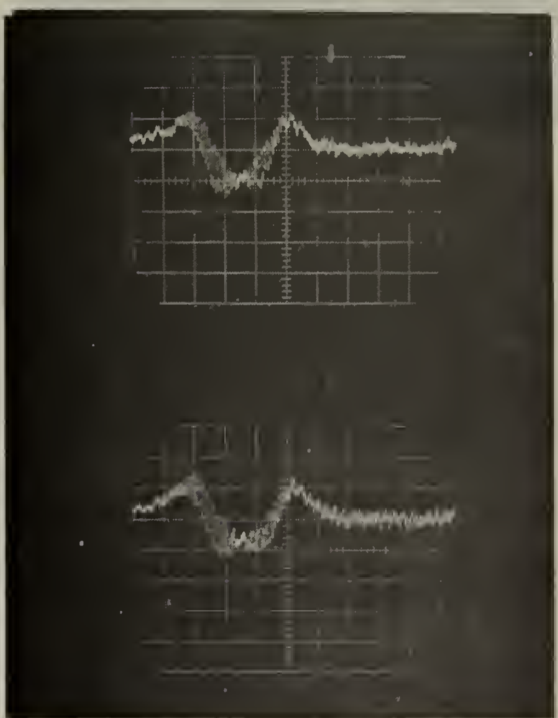
Figure 9. Pressure Signature of Model with Hemispherical Bow and Taper Stern at Speed 1.57 m/s, in Concentrations of 0,50, and 100 wppm



0 wppm

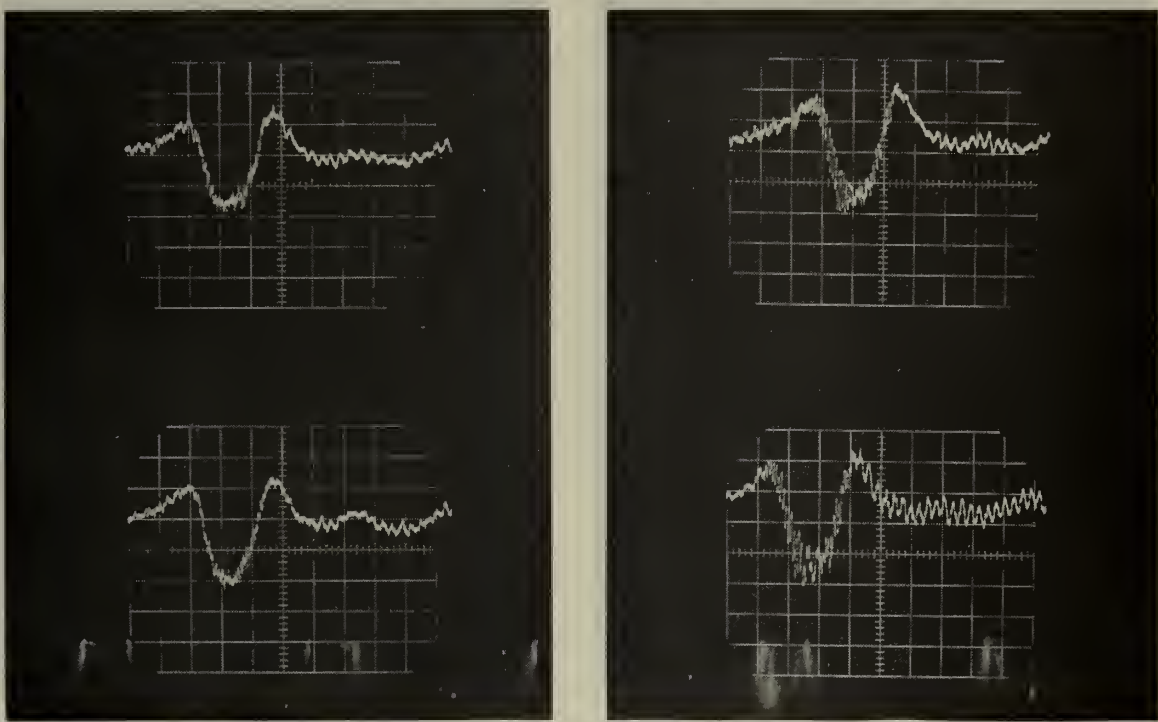


50 wppm



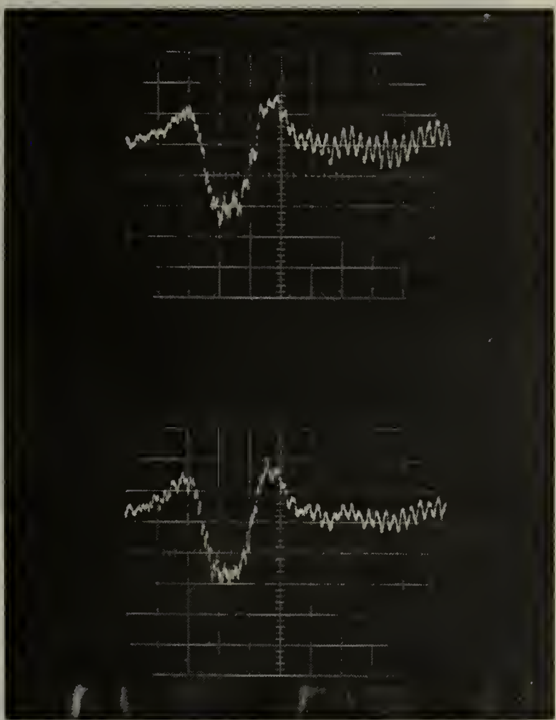
100 wppm

Figure 10. Pressure Signature of Model with Hemispherical Bow and Taper Stern at Speed 1.84 m/s in Concentrations of 0,50, and 100 wppm

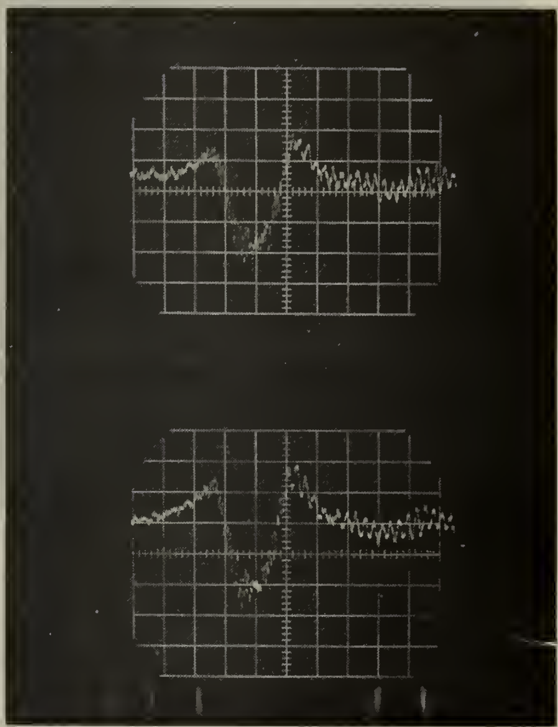


0 wppm 100 wppm

Figure 11. Pressure Signature of Model with Hemispherical Bow and Taper Stern at Speed 2.36 m/s in Concentrations of 0 and 100 wppm

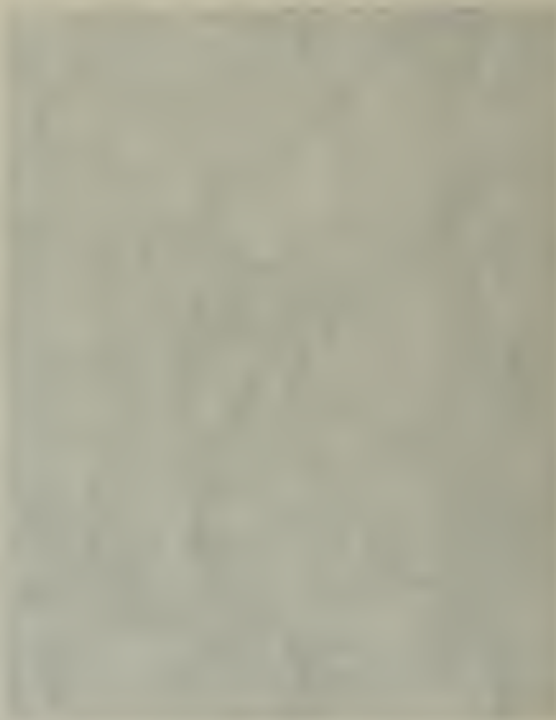


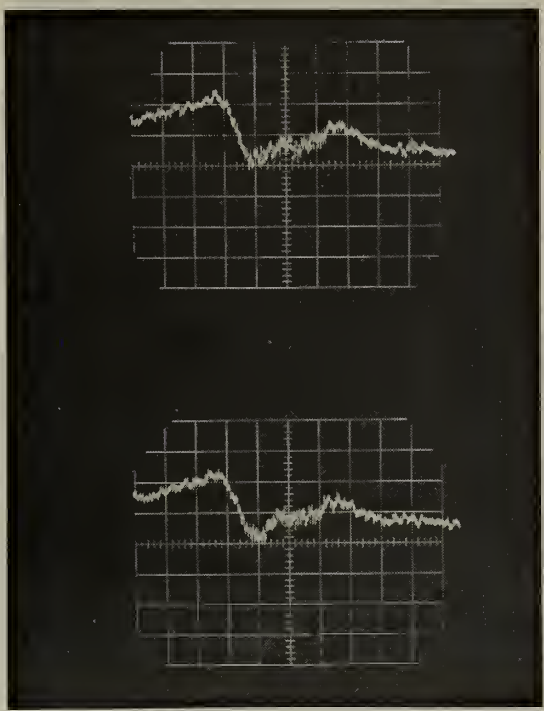
50 wppm



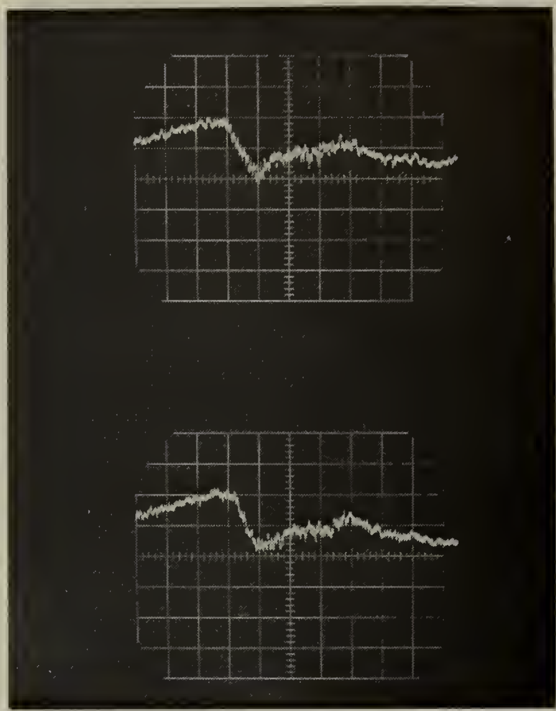
200 wppm

Figure 12. Pressure Signature of Model with Hemispherical Bow and Taper Stern at Speed 2.36 m/s in Concentrations of 50 and 200 wppm

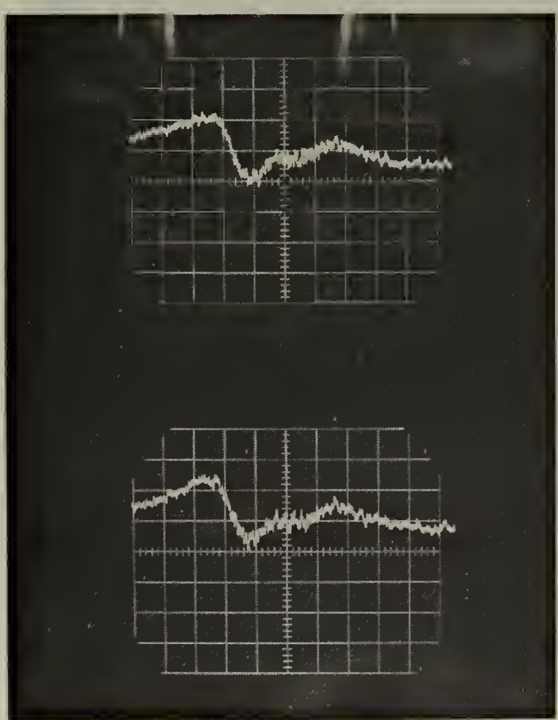




0 wppm

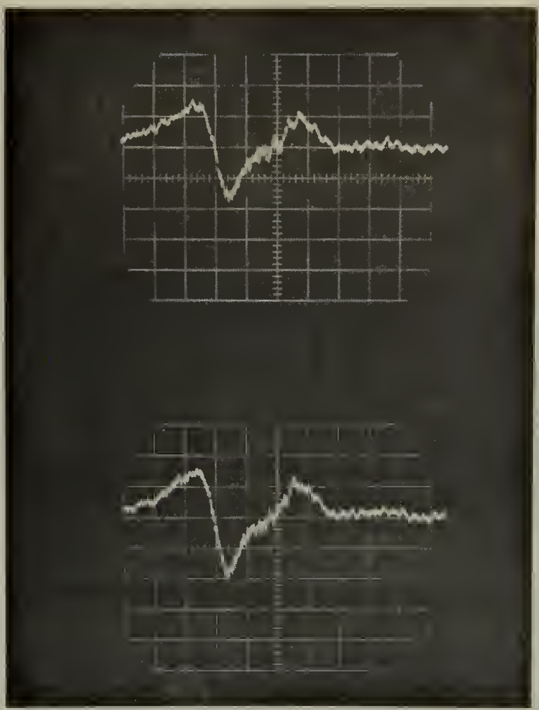


50 wppm

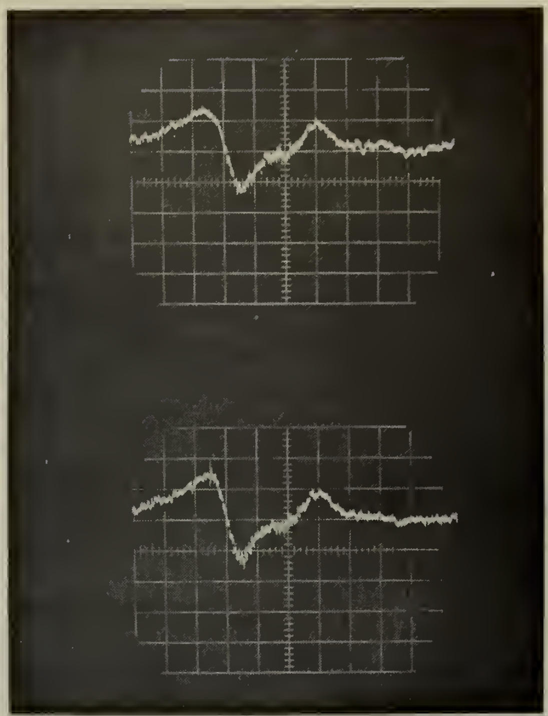


100 wppm

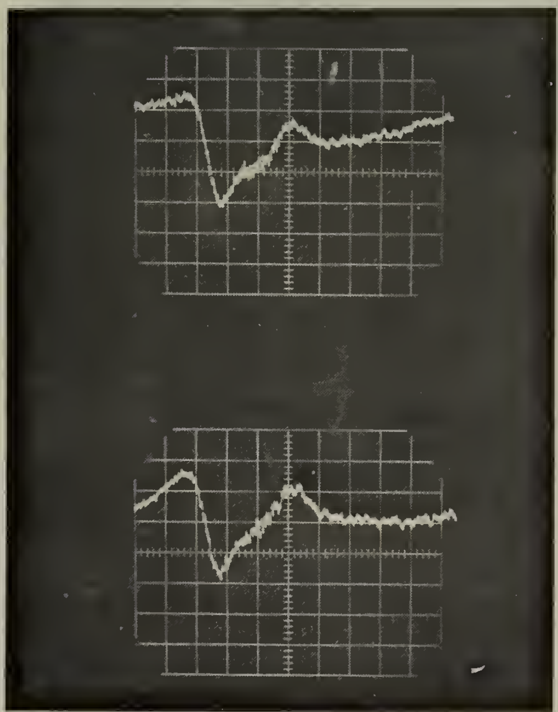
Figure 13. Pressure Signature of Model with Square Bow and Taper Stern at Speed 1.57 m/s in Concentrations of 0,50, and 100 wppm



0 wppm

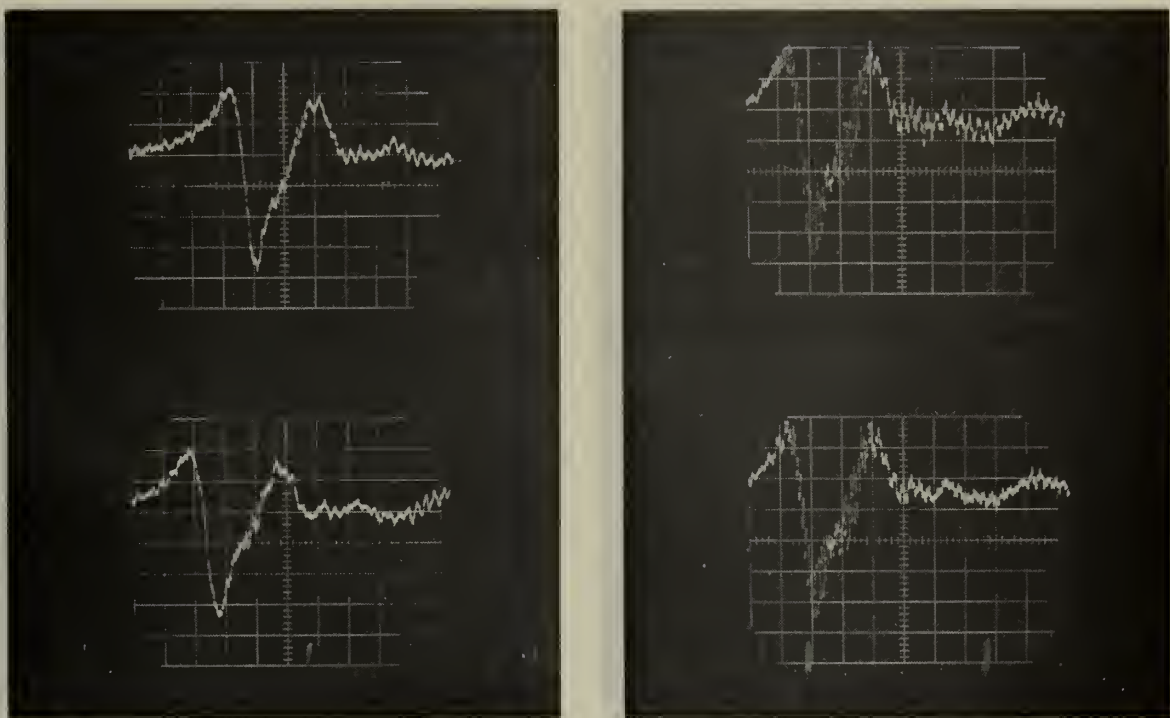


50 wppm



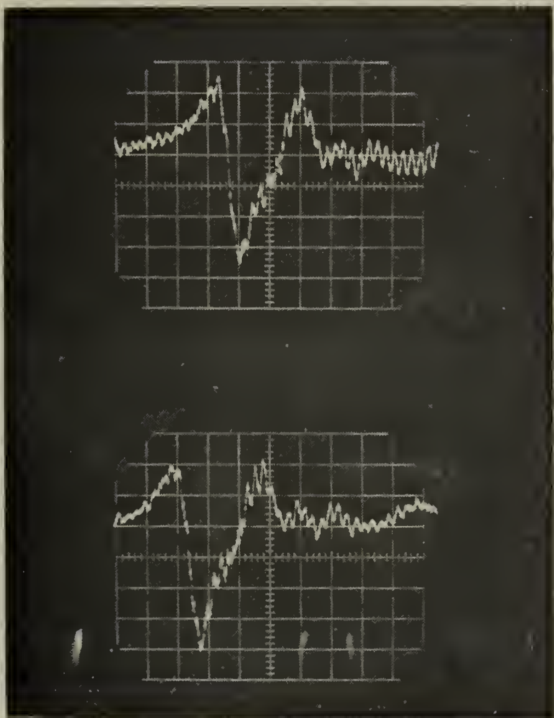
100 wppm

Figure 14. Pressure Signature of Model with Square Bow and Taper Stern at Speed 1.84 m/s in Concentrations of 0,50, and 100 wppm

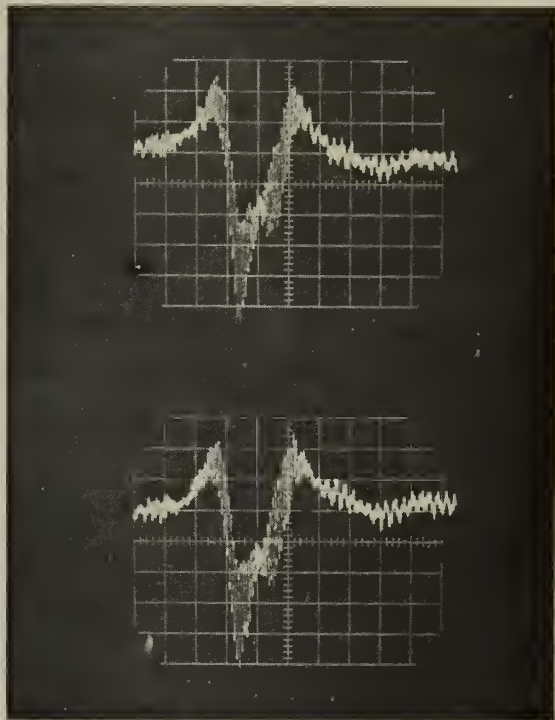


0 wppm 100 wppm

Figure 15. Pressure Signature of Model with Square Bow and Taper Stern at Speed 2.36 m/s in Concentrations of 0 and 100 wppm



50 wppm



200 wppm

Figure 16. Pressure Signature of Model with Square Bow and Taper Stern at Speed 2.36 m/s in Concentrations of 50 and 100 wppm

B. RESULTS OF STRUT-CONTRIBUTION DATA RUNS

When data runs were made using the strut fitted with a flush end cap instead of the model there was no indication above noise that the strut had passed the hydrophone at the two lower speeds. At the high speed of 2.36 meters/second the pressure signature of the strut was barely discernable.

C. PHOTOGRAPHIC RESULTS OF FREE SURFACE EFFECT

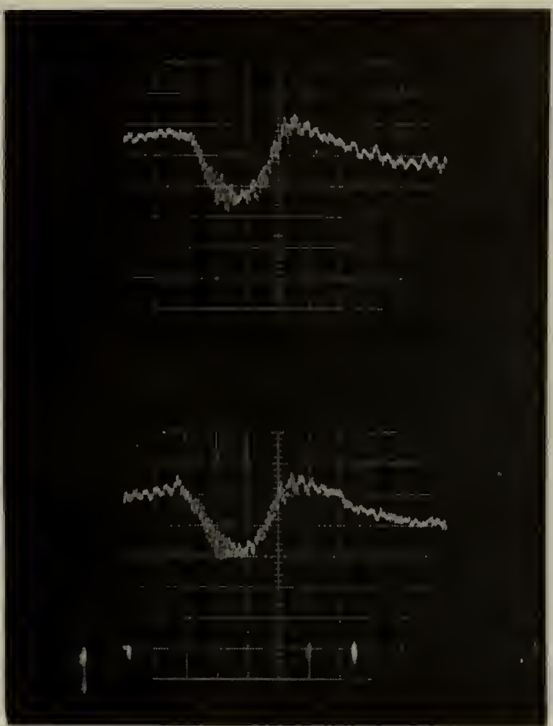
The data runs made at double the normal water depth to determine the effect of the free air-water interface show little difference when compared with identical runs made at the normal depth (7¼ inches). Figure 17 shows the pressure signatures obtained at velocity 1.84 meters/second, and Figure 18 shows those obtained at velocity 2.36 meters/second.

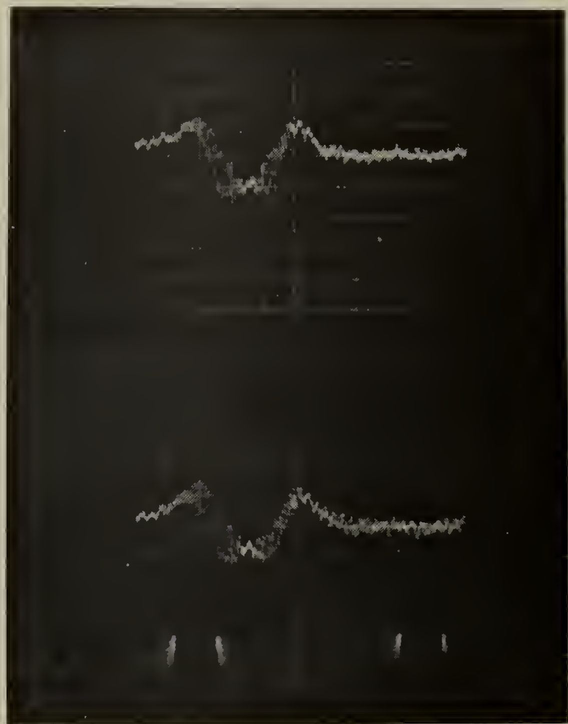
D. A SINGLE ANOMOLOUS RESULT

Visual examination of the photographs showed no significant alteration of the pressure signature due to polymer addition except at a concentration of 50 wppm and velocity 1.84 meters/second during forced fluid sepration flow conditions (square bow). At this concentration and velocity an overall decrease in the pressure signature magnitude appears to have taken place; this is particularly noticeable in the slope of the pressure signature when it first becomes negative.

E. SUBSEQUENT INVESTIGATION

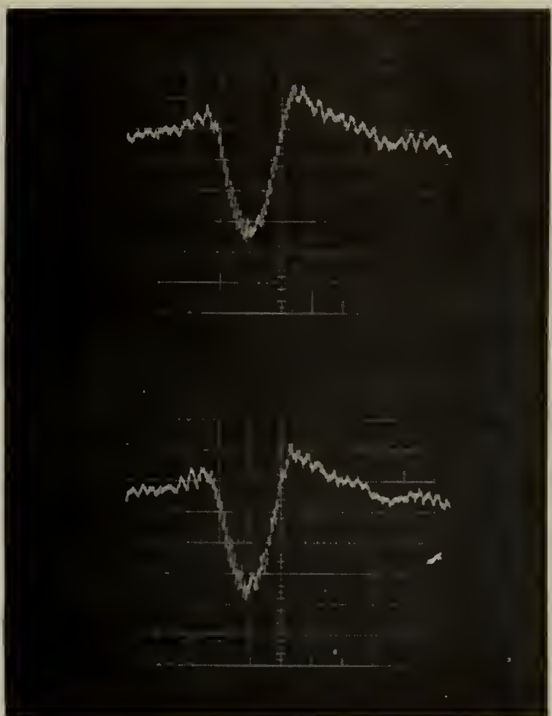
Because the only change in the pressure signature appears to have taken place during forced fluid separation flow conditions at

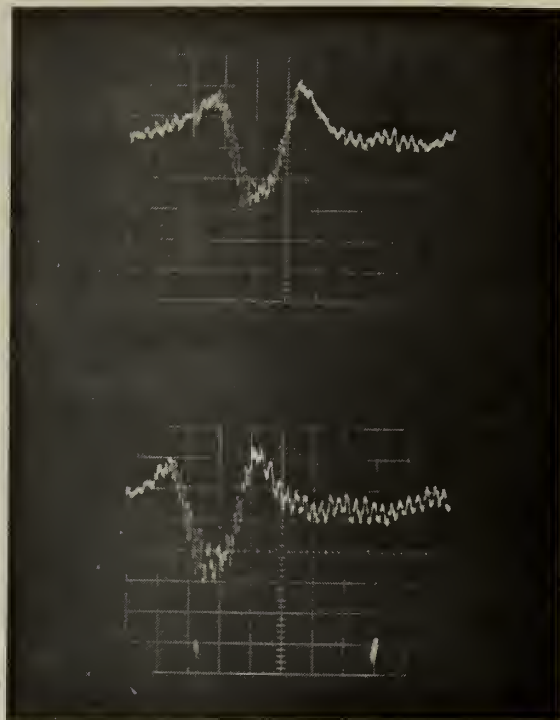




Fluid Level = 7¼ in. Fluid Level = 14½ in.

Figure 17. Pressure Signature Obtained at Speed 1.84 m/s for Model with Hemispherical Bow and Taper Stern at Concentration 100 wppm and Two Different Fluid Levels





Water Level = 7¼ in.   Fluid Level = 14½ in.

Figure 18. Pressure Signature Obtained at Speed 2.36 m/s for Model with Hemispherical Bow and Taper Stern at Concentration 100 wppm and Two Different Water Levels

concentration 50 wppm and velocity 1.84 meters/second, determination of whether this phenomenon was repeatable was made over a close range of concentrations and velocities surrounding 50 wppm and 1.84 meters/second. Consequently, data runs, per the originally stated method, were conducted at concentrations of 0, 30, 50, and 70 wppm of PolyOx WSR-301 and at velocities of 1.60, 1.84, and 2.00 meters/second. All runs were made utilizing the model with square bow and taper stern as in the initial investigation.

Careful visual analysis of the photographs obtained showed that, indeed, no change in the pressure signatures was apparent. The results of two data runs at concentration 50 wppm and speed 1.84 meters/second compared exactly with those obtained in the original experiments for concentrations other than 50 wppm.

It must therefore be concluded that the apparent pressure signature decrease which occurred was a singular artifact, due to a particular set of dynamic fluid conditions which existed at the particular times and in those fluid sections where the data was taken. The polymer could have enhanced these conditions, but this is indeterminant.

VII. CONCLUSIONS

A. SIGNIFICANCE AND FUTURE APPLICATION OF APPARATUS AND METHOD DEVELOPED

An apparatus and method have now been developed and tested by which the pressure signatures of various models can be investigated. In particular, because of the small size of the apparatus and the resulting economy, this technique may be preferable to the relatively large scale and expensive modeling presently necessary to confirm a theoretical pressure signature.

B. PRESSURE SIGNATURE VARIATION WITH POLYMER ADDITION

Qualitative examination of the pressure signatures obtained under laminar flow and forced fluid separation flow conditions shows no effect which is attributable to the addition of PolyOx WSR-301 into solution with water. Since there is no change evident, this reenforces the theory that common drag-reducing agents effect only the boundary layer conditions within a flow, and that decreased flow noise is the direct result of a decrease in the turbulent boundary layer.

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13. ABSTRACT

A whirling arm apparatus was successfully developed and tested for investigating the pressure signatures of submerged bodies of length less than one foot. The pressure signature of a cylindrical body, nine inches long and one inch in diameter, moving at constant velocities of 1.57, 1.84, and 2.36 m/s in aqueous solutions of Poly(Ethylene Oxide) WSR-301 at concentrations of 0, 50, 100 and 200 wppm was investigated under laminar flow conditions; Reynolds numbers, based on length, were in the range from 3.6×10^5 to 5.4×10^5. A regular laminar flow pattern was investigated utilizing the body with a hemispherical bow and tapered stern, and a laminar flow pattern with forced fluid separation followed by reattachment was investigated by utilizing a squared-off bow and a tapered stern. A Barium Titanite crystal hydrophone was used as the sensor. No apparent difference in the pressure signature was found which could be attributed to the addition of the polymer into solution.

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